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A METHOD AND APPARATUS FOR DETECTING DEFECTS OF AT LEAST
ONE ROTOR OF A ROTARY WING AIRCRAFT

The present invention relates to a method of
detecting defects, if any, of at least one rotor of a

5   rotary wing aircraft, in particular a helicopter, and for
adjusting the rotor. The invention also relates to
apparatus for determining defects and adjustment values
for adjustment parameters of such a rotor.

In the context of the present invention:

10   · the term "detecting defects of the rotor" is used
to mean detecting defective parts of said rotor (e.g. in
non-exhaustive manner, a ball bearing, a lag damper, an
undercut leading edge of a blade, a pitch-link or any
other mechanical part presenting a defect, that might

15   generate an increased level of rotor vibration), which
elimination of said defects corresponding to replacing
the defective parts; and

· the term "adjusting the rotor" is used to mean
adjusting particular elements of the rotor (e.g.

20   compensating tabs or weights mounted on the rotor blades)
for the purpose of reducing and minimizing the vibration
of at least one portion (e.g. the pilot's seat) of a
rotary wing aircraft.

Such vibration constitutes a major problem that

25   needs to be countered, since such vibration leads to:

· alternating stresses throughout the aircraft
giving rise to fatigue phenomena, and thus having a
direct influence on safety;

· vibrations in the fuselage which can reduce the

30   precision and the effectiveness of equipment, in
particular weapons, mounted on said fuselage; and

· vibrations in the cabin, which is naturally very
troublesome for the comfort of the pilots and the
passengers.

35   Document EP-0377 666 (US-4 937 758) discloses a
system and a method for minimizing vibration and stress
within an apparatus such as a helicopter having a rotor

with rotary blades disposed thereabout. Said method includes the steps consisting in (and the system includes means for):

a) calculating the effects of unit mechanical
5 adjustments on the force and the moment exerted by the rotor on the support structure. Each specific helicopter possesses its own computer file, which remains with the helicopter throughout its lifetime. Thus, each helicopter with a serial number has its own particular
10 database (i.e. which applies to that helicopter only) containing a vibration profile of the helicopter over time, accompanied by descriptive information relating to flight test conditions and to maintenance actions;

b) determining at least three force components and
15 at least three moment components generated by the rotor;

c) detecting the angular position of a shaft of said rotor;

d) processing the signals representing the force and moment components and the signals representing the
20 angular position of said shaft in order to produce the Fourier coefficients of said forces and moments;

e) determining the optimum mechanical adjustments for the rotor in order to minimize the vibrations in the support structure of the rotor, said optimum adjustments
25 being deduced from said Fourier coefficients of the movements produced and from said calculated effects of the unit mechanical adjustments of the blades; and

f) prescribing blade adjustments in agreement with said optimum mechanical adjustments.
30 The method of minimizing vibration, as described in that document EP-0 377 666 presents the following characteristics in particular:

· on each occasion it applies to a single helicopter only, for which it is necessary to begin by calculating
35 the effects of mechanical adjustments on the force and the moment exerted by the rotor;

· it requires forces and moments to be obtained that are due firstly to a non-adjusted rotor and secondly to each of the various adjustments. These forces and moments can be deduced from measurements performed by measurement means such as accelerometers or strain gauges fixed on the structure, with the deformations thereof being measured;

· it implements an approximation by assuming that the fuselage of the helicopter is a rigid body presenting six degrees of freedom (whereas, in fact, the helicopter is a deformable body which is subjected to external excitations coming in particular from the rotors and from various aerodynamic forces), and it seeks to correct the movements of said rigid body in three dimensions;

· in order to be implemented, it requires knowledge of the exact locations in the helicopter cabin of said measurement means (accelerometers, strain gauges, ...) relative to the center of gravity of the helicopter; and

· in order to calculate the mechanical adjustments, it uses an ordinary linear system with influence coefficients.

That prior art method (or system) presents several major drawbacks:

A/ firstly, by assuming that the helicopter is a rigid body and thus by trying to minimize the vibrations of its structure without taking account of any possible deformations thereof, said prior art method is not capable of achieving optimum adjustment of the rotor;

B/ secondly, as mentioned above, it is necessary to know the actual exact location of the measurement means relative to the center of gravity of the helicopter.

Consequently, there must be no errors made while putting said measurement means in the locations that are provided for this purpose.

In addition, as the position of the center of gravity of the helicopter varies as a function of its loading, and since the locations of measurement means

that are installed once only, any subsequent variation of the weight or the weight distribution within the helicopter will lead specifically to errors in implementation of the method, thereby reducing the

5 accuracy of the adjustment achieved; and

C/ thirdly and above all, that prior art document recommends adjusting a helicopter rotor for the purpose of reducing vibration without taking any account of the defects, if any, of the rotor, i.e. without verifying

10 whether parts such as the ball bearings or the dampers of said rotor are defective and are responsible at least in part for the vibration that is to be reduced.

It is known that with defects of the above type, the intensity of the vibration due to the defects varies,

15 generally as a function of the speed of rotation of the rotor. Consequently, by using the method disclosed in document EP-0 377 666 to adjust a rotor presenting at least one such defect, while taking no account of the defect, the vibration is indeed usually reduced for the

20 speeds of rotation that were taken into account for the adjustment, but vibration is not minimized for all speeds of rotation. On the contrary, the adjustment can even have the opposite effect, i.e. under certain conditions, it can lead to vibration being increased at other speeds

25 of rotation.

Furthermore, it can happen that the vibration due to a defect of the rotor is so great that it becomes impossible to identify the influence matrix that enables the above-mentioned method to be implemented.

30 Consequently, when defects exist on the rotor, the solution recommended by document EP-0 377 666 is generally not applicable since:

· it is generally not possible to reduce the levels of vibration throughout the range of flying conditions in

35 order to guarantee satisfactory comfort; and/or

· it is often very difficult and sometimes
impossible to identify the influence matrix needed for
implementing said method.

An object of the present invention is to remedy

5   those drawbacks. The invention relates to a method for
at least detecting, in simple and effective manner, any
defects of at least one rotor of a rotary wing aircraft,
in such a manner as to be capable of canceling or at
least minimizing the vibration (due to such defects) in

10   at least one portion of said aircraft.

To this end, according to the invention, said method
is remarkable in that:

I - in a preliminary step, in which a reference
aircraft is used corresponding to a rotary wing aircraft

15   of said particular type, having its rotor without defect
and adjusted to a reference setting for which the
vibration level of at least one portion of said aircraft
is at a minimum, the following operations are performed:

a) taking at least a first series of measurements on

20   said reference aircraft, by measuring, during particular
operation of said reference aircraft, the values of at
least two accelerations which are measured at arbitrary
locations of said portion of the reference aircraft and
which are representative of the vibration generated at

25   said portion of the reference aircraft:

α) firstly using the rotor of the reference
aircraft which is without defect and which is adjusted on
said reference setting; and

β) secondly by introducing defects into said

30   rotor; and

b) on the basis of said first series of acceleration
measurements and assuming that the aircraft is a
deformable body, determining a neural network that
illustrates the relationships between said accelerations

35   and at least said defects; and

II - in a later step, for at least defecting any defects
of the rotor of a particular rotary wing aircraft of said
aircraft type, the following operations are performed:

a) taking a second series of measurements on said
5   particular aircraft by measuring the values of at least
some of said accelerations at said portion of the
aircraft during particular operation of said aircraft;
and

b) on the basis of said second series of
10   acceleration measurements and on the basis of the neural
network determined in step I/b), detecting any defects of
said rotor.

Thus, by means of the invention, it is possible to
detect rotor defects (i.e. defective parts) accurately.
15   Eliminating such defects (i.e. replacing the defective
parts) then makes it possible to reduce and possibly to
minimize or even cancel the vibrations in said portion
(cabin, ...) of the aircraft. Rotor parts that are
likely to be defective, include in particular the ball
20   bearing of the mast and the lag dampers of the blades.

In addition to detecting defects, the method in
accordance with the present invention also makes it
possible in simple and effective manner to adjust said
rotor for the purpose of minimizing (or even canceling)
25   all vibration of said portion of the aircraft.

To this end, said above-specified method is
remarkable, according to the invention, in that:
I - in the preliminary step, the following operations are
performed:
30   a) taking said first series of measurements on said
reference aircraft in a situation γ) in addition to said
situations α) and β), by measuring, during the particular
operation of said reference aircraft, the values of said
accelerations which are representative of vibration
35   generated at said portion of the reference aircraft, and
varying the adjustment values of a plurality of

adjustment parameters of said rotor in said situation γ);
and

     b) on the basis of said first series of acceleration
measurements, determining said neural network which
illustrates the relationships between firstly said
accelerations and secondly said defects and said
adjustment parameters; and
II - in the later step, which is additionally for
adjusting the rotor of the particular rotary wing
aircraft of said type of aircraft, after said operations
a) and b), performing the following operations:

     c) on the basis of said second series of
acceleration measurements and of the neural network
determined in step I/b), determining the adjustment
values of at least some of said adjustment parameters
which enable the level of vibration of said portion of
the aircraft to be minimized; and

     d) applying to the rotor of the aircraft the
adjustment values as determined in this way for said
adjustment parameters.

     Thus, by means of the invention, it is possible to
adjust accurately the adjustment parameters of the rotor
as specified below in such a manner as to reduce
vibration at the at least one portion of the aircraft, in
particular in the cabin, but also in the tail boom or the
fuselage, for example.

     Furthermore, by means of the invention,
implementation of the method requires a small number of
test operations, in particular of test flights, using a
reference aircraft that is without defects and that is
preadjusted by the usual known means and that is of the
particular type under consideration, in order to
determine said neural network for subsequent use when
making adjustments. The neural network can be used to
analyze the rotor of any aircraft that is of the same
type as the reference aircraft.

In order to show clearly the characteristics and the advantages of the method in accordance with the present invention, the following major differences between this method and the above-mentioned method described in

5   document EP-0 377 666 are listed:

· unlike the above-mentioned prior art method, the method in accordance with the invention makes it possible to detect the defects, if any, of the rotor prior to undertaking any adjustment, thus making it possible to

10   obtain an adjustment that is optimal;

· the present invention assumes that the aircraft is a deformable body and not a rigid body having six degrees of freedom, thus making it possible firstly for account to be taken of structural deformations which are very

15   large in the vibration response of the aircraft, and secondly for it to be unnecessary to use six measurement means;

· the measurements of at least two accelerations are sufficient for implementing the present invention. In

20   addition, it is not necessary to know the locations of the accelerometers taking the measurements, whereas the prior art method uses six measurement means whose locations must be known accurately relative to the center of gravity of the helicopter, which leads to the above-

25   mentioned drawbacks;

· the method in accordance with the present invention processes the measured accelerations directly. In contrast, said prior art method begins, on the basis of the measurements taken by the accelerometers or the

30   strain gauges, by calculating the forces and the moments that are exerted by the rotor, prior to subsequently processing these forces and moments;

· the method in accordance with the invention makes use of a neural network which defines relationships that

35   are non-linear and which is adaptable, as specified below, whereas the prior art method merely makes use of

an ordinary influence matrix which naturally defines linear relationships only; and

· said neural network as determined once and for ever during the preliminary step I can be used

5 subsequently for detecting defects of a rotor and for adjusting the rotor of any aircraft of the same type as the aircraft used during the preliminary step I. In contrast, the influence matrices used by said prior art method need to be determined initially for each

10 particular helicopter whose rotor is to be adjusted, and that is lengthy and tedious.

A preferred implementation consists, between steps II/b) and II/c), in eliminating any defects that have been detected in said step II/b), and in taking a new,

15 second series of measurements for use in step II/c) for determining the adjustment parameters, i.e. the defects are eliminated (the defective parts are replaced) once they have been determined, and prior to taking the measurements a second time in order to determine the

20 adjustment parameters. This intermediate step is not always necessary. Nevertheless, it makes it possible to improve the effectiveness of the adjustment by performing the adjustment on an aircraft having a rotor that is without defect (i.e. without any defective part).

25 In addition, and advantageously, the adjustment elements defining said adjustment parameters comprise at least the following elements of the rotor of the aircraft:

· at least one balance weight preferably on the

30 sleeve of each of the blades of the rotor;

· a pitch-link on each of the blades of the rotor, except for one blade which represents a reference blade; and

· at least one compensating tab on the trailing edge

35 of each of the blades of the rotor.

Furthermore, in a first implementation for use with the advance and lift rotor of a rotary wing aircraft,

during said step I/a), said first series of measurements are taken during at the following test flights:

· a reference flight with the rotor adjusted to said reference setting;

· flights with known defects deliberately introduced into the rotor;

· a flight with a first particular mis-adjustment of at least one balance weight of a blade;

· a flight with a second particular mis-adjustment of at least one of the blade pitch-links, after eliminating said first mis-adjustment; and

· a flight with a third particular mis-adjustment of at least one compensating tab provided on the trailing edge of one of the blades, after eliminating said second mis-adjustment.

In which case, and advantageously, at least one of said test flights during step I/a) and of said measurement flights during step II/a) includes the following configurations, during which measurements are taken:

· a stationary flight configuration;

· a configuration of flight at about 50 meters per second (m/s), i.e. about 100 knots;

· a configuration of flight at continuous maximum power; and

· a test on the ground with the rotor revolving.

In addition, for an advance and lift rotor of a rotary wing aircraft, said portion of the aircraft where the values of said accelerations are measured is the cabin of the aircraft. However, for an anti-torque tail rotor of a rotary wing aircraft, said portion of the aircraft at which the values of said accelerations are measured is the tail boom of the aircraft.

In a second implementation, for an anti-torque tail rotor of a rotary wing aircraft, at least one of said first and second series of measurements is taken with the aircraft on the ground and the tail rotor in operation.

Furthermore, and advantageously, during step I/b), account is taken of the following additional assumptions for determining said neural network:

· the rotor is not isotropic;

5 · the relationships between firstly the defects and the adjustment parameters and secondly the acceleration values are linear; and

· the vibration level existing at any particular point of the aircraft (which is assumed to be deformable) 10 corresponds to the sum of the elementary vibrations generated at said particular point and caused by the defects and the mis-adjustment of said adjustment parameters.

In addition, and preferably, during step II/c), the 15 adjustment value α of an adjustment parameter is determined by minimizing the following expression:

$$\left\| R\left(\alpha\right) + \gamma \right\|^2$$

in which:

· R is the corresponding transfer function of said 20 measurement network; and

· γ is a vector containing the vibration level representative of the measurements taken in step II/a).

Furthermore, in the invention, during step II/c), it is also possible:

25 · to display the adjustment values that have just been determined, in particular on an ordinary screen; and/or

· to record said values on an ordinary recording medium so as to be able to use them subsequently, in 30 particular to predict future levels; and/or

· to display the acceleration values after the adjustments as predicted by the neural network.

The same can be done during step II/b) for rotor defects.

35 Furthermore, in the invention, it is possible to provide a resetting stage in order to take account of

features specific to a given aircraft, during which the following operations are performed:

a) taking a third series of measurements while causing the adjustment values of only some of said
5   adjustment parameters to vary; and

b) adjusting said neural network on the basis of said third series of measurements, for the corresponding relationships which relate to the adjustment parameters for which the adjustment values have been varied.

10   The present invention also provides apparatus for detecting defects and for determining adjustment values for adjustment parameters of a rotor of a rotary wing aircraft.

According to the invention, said apparatus is
15   remarkable in that it comprises:

· a calculator suitable for automatically determining said defects and said adjustment values, in the manner specified above, on the basis of a neural network and on the basis of measurement values of a
20   second series of measurements;

· interface means between said apparatus and an operator, enabling the operator to input said measurement values of said second series of measurements into said calculator; and

25   · indicator means for informing said operator of the defects and the adjustment values determined by said calculator.

In addition, and advantageously, said calculator is suitable for determining said neural network on the basis
30   of measurement values of a first series of measurements, and said interface means further enables said operator to input into said calculator said measurement values of said first series of measurements.

Furthermore, said device may also include a memory
35   for storing said neural network.

The figures of the accompanying drawings will make it well understood how the invention can be implemented.

In these figures, identical references designates elements that are similar.

Figure 1 is a diagram showing a rotary wing aircraft, to which the present invention is applied.

5   Figure 2 is a block diagram of apparatus in accordance with the invention for detecting defects (defective parts) and for determining the adjustment values (adjustment parameters) of at least one rotor of a rotary wing aircraft.

10 Figure 3 is a fragmentary diagrammatic view of a rotor blade provided with adjustment elements in accordance with the invention.

The rotary wing aircraft, specifically a helicopter 1, shown in Figure 1 and to which the present invention
15 is applied, comprises in the usual way a fuselage 2 having the cockpit 3 disposed in the front portion thereof. The intermediate portion 4 of said fuselage includes a power plant 5 suitable for driving rotation of the main advance and lift rotor 6 made up of blades 7.
20 The fuselage is extended up by a tail boom 8, having disposed at the free end thereof a fin 9 provided with a rudder 13. In addition, at the aft end of the tail boom 8, e.g. at the base of the fin 9, there is provided an anti-torque tail rotor 10 of variable pitch, driven in
25 rotation by the power plant 5 via a rotary shaft 11 and including blades 12. Said anti-torque rotor 10 is preferably ducted in a fairing constituted by the base of the fin 9.

The present invention relates to a method of
30 detecting defects of at least one of the rotors 6 and 10 of the helicopter 1 in order to adjust said rotor 6 and 10 in order to obtain a low level of vibration in 1 Ω, in particular, where Ω is the speed of the rotor, in the three directions of the helicopter 1 (axial, lateral, and
35 vertical) in order to achieve optimum comfort and maximum operating safety. This adjustment is performed systematically after manufacture and thus prior to the

first flight of the helicopter 1, and also after any
maintenance operation on a rotor 6, 10. It may also be
performed at any time, if so desired, or if the operation
of the rotor 6, 10 makes it necessary.

5   To do this, the method in accordance with the
invention presents at least:
        · a preliminary step or "training step" I; and
        · at least one later step II of eliminating defects,
and possibly of actual adjustment.

10   In the context of the present invention, a defect of
the rotor 6, 10 corresponds to a defective state of a
part of said rotor (in particular constituting a source
of vibration), specifically a lag damper of a blade 7 or
a bearing of the mast 6A of the rotor 6.

15   According to the invention, in said preliminary
step, in which use is made (exclusively) of a reference
helicopter corresponding to a helicopter of some
particular type (Ecureuil, Puma, ...) under consideration
for adjustment, and having its rotor 6, 10 without defect

20   (no faulty part) and adjusted on a reference setting, for
which the level of vibration of at least a portion of
said helicopter 1 (cabin 3, tail boom 8, ...) is at a
minimum:

        a) at least a first series of measurements are taken

25   on said reference helicopter, measuring during a
particular operation of said reference helicopter 1, the
values of at least two accelerations which are measured
at arbitrary points of said portion 3, 8 of the reference
helicopter and which are representative of vibration

30   generated at said portion of the reference helicopter:
        α) with the rotor 6, 10 of the reference
helicopter 1 which is adjusted on said reference setting;
        β) by introducing defects into said rotor 6,
10; and

35   γ) by varying the adjustment values of a
plurality of adjustment parameters of said rotor; and

   b) from said first series of acceleration
measurements, and taking into consideration that the
helicopter 1 is a body that is deformable (i.e. non-rigid
or presenting a certain amount of flexibility), a neural
5   network is determined as described below, which neural
network illustrates the relationships between firstly
said accelerations, and secondly said defects and said
adjustment parameters.

   In addition, in accordance with the invention, in a
10   later step II, in order to detect possible defects and in
order to adjust the rotor of any particular helicopter 1
of said type (Ecureuil, Puma, ...):

   a) a second series of measurements are taken from
said particular helicopter 1 whose rotor 6, 10 is to be
15   adjusted, by measuring the values of at least some of
said accelerations at said above-mentioned portion
(cabin, ...) of said particular helicopter 1, during a
particular operation of said particular helicopter.
Amongst the accelerations measured during said first
20   series of measurements, use is preferably made of those
which are the most sensitive;

   b) on the basis of said second series of
acceleration measurements and the neural network
determined in step I/b), the defects, if any of said
25   rotor are detected;

   c) on the basis of said second series of
measurements and the neural network determined in step
I/b), the adjustment values of at least some of said
adjustment parameters are determined, enabling the level
30   of vibration of said portion of said helicopter to be
minimized; and

   d) the adjustment values as determined in said way
for said adjustment parameters are applied to the rotor
6, 10 of said helicopter 1.

35   The helicopter 1 shown in Figure 1 may be a
reference helicopter or a helicopter for adjustment.   In

order to simplify the description, reference is made to
Figure 1 in both cases.

It is recalled that a neural network is usually made
up of a set of elements operating in parallel and such
5   that for data inputs, the outputs of the set are
characterized by the network. These elements take their
inspiration from biological nerve systems. As with
biological neurons, the functions of the network are
highly determined by the connections between elements.
10   It is thus possible to "train" a neural network so that
it is capable of accomplishing some particular function
by adjusting the values of the connections (known as
"weights") between the elements. This "training" is done
or adjusted so that for a given input the network
15   delivers a specific output. Concerning neural networks,
reference can be made for example to an article entitled
"Learning representation by back-propagation errors" by
D. Rumlhart, G. Hinton, and R. Williams, published in the
review Nature, 1996, Vol. 323, pp. 533 to 536.
20   As mentioned above, for a given type of helicopter
the training can be performed once only during said
preliminary training stage. For this purpose, the
defects and adjustment parameters on the rotor are
modified in controlled manner and the response of the
25   helicopter to such modifications is determined. The
relationships between firstly the defects and the
variations in the adjustment parameters at the rotor, and
secondly the vibration at various points of the
helicopter are then determined. These relationships,
30   represented mathematically by the neural network, are the
basic relationships for a given type of helicopter
(Ecureuil, ...). Subsequently they are used, if
necessary, to minimize fuselage vibrations (1 Ω, 2 Ω) at
as many points is desired, along all three axes, with
35   this being done in one or two flights only.

By varying each of the above-specified adjustment
parameters of the rotor one by one (and also the defects

one by one), and by recording the vibration (acceleration) differences relative to the reference at a plurality of judiciously chosen points of said portion of the helicopter, in particular the cockpit, the network R

5   is obtained. For each operating configuration and for each harmonic (obtained by the Fourier transform), this network gives the relationships between each measurement point and each adjustment parameter and each defect.

The neural network (specific to one type of
10 helicopter 1) is of the "feed-forward" type constituted by N_{ce} input cells ($N_{ce} = N_p$ adjustment parameters $\times N_b$ defects $\times b$ blades), without bias, and possessing the identity function at its activation function. The output layer is formed by N_{cs} cells ($N_{cs} = N_a$ accelerometers $\times$ C
15 flight configurations $\times$ H harmonics for the real part and the imaginary part at each point) likewise having the identity function as its activation function, and still without bias.

According to the invention, each defect which is to
20 be sought out subsequently is initially identified. Taking the example of a blade lag damper, the following operations are thus performed:

   - a damper, presenting the defect that is to be detected (if it exists) on other helicopters, is
25 installed on the reference helicopter;

   · on the ground with the rotor turning, or possibly in flight if the state of the damper makes that possible, the vibrations associated with said defect are recorded and the signature of the defect in terms of amplitude and
30 phase is established, which signature is distinguished from the defect-free reference type signal. It constitutes a kind of training algorithm which the neural network is going to be made to learn. Thus, a neural network will be available that is specialized and that
35 knows how to recognize such a defect; and

   · in operation, the detected defect signature is recognized by the neural network, in application of

appropriate criteria, from defects in a list of pre-established defects, with this being because of the particular amplitudes or phase offsets of the signals coming from the detectors (accelerometers, ...).

5   The preliminary training step I uses a conventional minimizing algorithm using the conjugate gradient method.

Said neural network is calculated automatically by a calculator 15, e.g. a microcomputer, which forms part of apparatus 16 in accordance with the invention, shown

10   diagrammatically in Figure 2 and further comprising:

· interface means 17, e.g. a keyboard, which is connected via a connection 18 to the calculator 15 and which enables an operator to input data into said calculator 15, and in particular the measurement values

15   of said first and second series of measurements; and

· indicator means 19, e.g. a display screen or audible indicator means, which are connected by a connection 20 to the calculator 15 and serve to inform the operator of the results of the processes performed by

20   the calculator 15, and in particular of the adjustment values for the adjustment parameters.

Thus, by means of the invention, it is possible to detect defects and to adjust precisely the adjustment parameters specified below for the rotor 6, 10 so as to

25   reduce vibrations in at least a portion of the helicopter 1, in particular in the cabin 3, but also on the tail boom 8, or the fuselage 2, for example.

It should be observed that the calculator 15 may operate not only in the frequency domain in a Fourier

30   representation, but also in the time domain.

Naturally, the present invention can be used merely for determining the defects of a rotor 6, 10 [in above-specified later step II: performing operations a) and b) only], without it being essential to adjust the rotor

35   [above-mentioned later step II: operations c) and d) not performed].

Furthermore, in a preferred embodiment, between steps II/b) and II/c), any defects detected in said step II/b) are eliminated and a new series of measurements are taken for use in step II/c) in order to determine the
5   adjustment parameters, i.e. once they have been determined, defects are eliminated (defective parts are replaced, e.g. a lag damper of a blade 7 presenting a loss of stiffness or of damping), with this being done prior to taking measurements again subsequently to
10   determine the adjustment parameters. This intermediate step is not always necessary. Nevertheless, it makes it possible to increase the effectiveness of the adjustment by performing the adjustment on an aircraft having a rotor (for adjustment) without defect.
15   In addition, by means of the invention, implementation of the method requires a number of test operations that is small, in particular a small number of test flights, as explained in greater detail below, using a reference helicopter which is pre-adjusted by known and
20   usual means and which is of a particular type, in order to determine said neural network which is used subsequently during later adjustments. The neural network may be used for adjusting the rotor 6, 10 of any helicopter 1 (including the helicopter that was used as
25   the reference helicopter), providing it is of the same type as the reference helicopter.
          Advantageously, in particular for adjusting the main rotor 6, said plurality of accelerations whose values are measured using ordinary accelerometers (some shown
30   diagrammatically at 21, 22, 23, and 24 in Figure 1) may comprise, by way of non-limiting example, at least some of the following accelerations in the cockpit 3 of the helicopter:
          · longitudinal, lateral, and vertical accelerations
35   at the floor of the cabin 3, substantially vertically beneath the mast 6A of the main advance and lift rotor 6

of said helicopter, one of said accelerations being
suitable for being measured by the accelerometer 21;

· the vertical acceleration of the pilot's seat; and
· the lateral and vertical accelerations of the co-
5   pilot's seat, measured by the accelerometers 22 and 23.

It is recalled that in the context of the present
invention, it is not necessary for the accelerometers to
be located at specific locations that are known
accurately. However, it can be advantageous to arrange
10   at least some of the accelerometers at vibration
antinodes in the floor of the helicopter 1.

In addition, in order to adjust the tail rotor 10,
accelerations are measured in particular of the tail boom
8 carrying the rotor 10, e.g. using the accelerometer 24.

15   In the invention, in order to adjust the rotor 6,
the adjustment elements which define said adjustment
parameters comprise at least the following usual elements
(associated with each of the blades 7 of the rotor 6 of
the helicopter 1):

20   · balance weights 25 which are preferably provided
at the sleeve 26 of each blade 7 of the rotor 6 and which
enable rotor unbalance to be minimized by shifting the
center of gravity along the span of the assembly
constituted by the blade, the sleeve, and the
25   corresponding portion of the hub;

· a pitch-link 27 which may be lengthened or
shortened for each blade 7 of the rotor 6, with the
exception of one of the blades which represents a
reference blade. It is known that by lengthening the
30   pitch-link 27, the pitch and thus the lift of the blade
is increased, and that by shortening the pitch-link 27,
lift is reduced; and

· compensating tabs 28 which are provided on the
trailing edge 29 of each blade 7 of the rotor 6 and which
35   enable differences in lift between the blades 7 to be
compensated.

In addition, in the invention, during step I/b), account is taken of the following additional assumptions when determining said neural network:

· the rotor 6, 10 is considered as being non-isotropic;

· the helicopter 1 is assumed to be a deformable body, for the first two harmonics of the frequency of rotation of the rotor 6, 10;

· the relationships between firstly the defects and the adjustment parameters, and secondly the acceleration values are non-linear; and

· the level of vibration that exists at any particular point of the helicopter 1 is assumed to correspond to the sum of the individual vibrations generated at said particular point and caused by the defects and mis-adjustments of said adjustment parameters.

Furthermore, in a first embodiment for adjusting the advance and lift rotor 6 of the helicopter 1, during said step I/a), said first series of measurements is taken during at least the following test flights:

· a reference flight with the rotor 6 adjusted to said reference adjustment (which enables vibration levels to be minimized);

· flights with selected defects of the rotor 6;

· a flight with a particular mis-adjustment of at least one balance weight 25 which is preferably provided on the sleeve 26 of one of the blades 7;

· a flight with a particular mis-adjustment of at least one pitch-link 27 of one of the blades 7; and

· a flight with a particular mis-adjustment of at least one compensating tab 28 provided on the trailing edge 29 of one of the blades 7.

Under such circumstances, and advantageously, at least one of said test flights performed in said step I/a) and said measurement flights performed in step II/a)

include the following configurations, during which measurements are taken:

   · a stationary flight configuration:

   · a flight configuration at about 50 m/s, i.e. about

5 100 knots;

   · a flight configuration at continuous maximum power; and

   · a test on the ground with the rotor revolving.

It should be observed that for the flights with

10 defects, the number of configurations can be small.

In this case (adjustment of the rotor 6), in addition, above-mentioned step II/b) of the method of the invention is implemented including the following operations:

15

A1/ <u>File processing</u>

Since the reference position of the rotor is different for each helicopter 1, it is necessary to reset measurements so as to conserve the same origin. Let α be

20 the angle (positive in the direction of rotation) between the reference position of the rotor and the reference blade, giving:

$$\varphi'_{c,a,h} = \varphi_{c,a,h} - h\alpha$$

where φ' and φ are respectively the phase of the

25 vibration level before and after resetting, <u>c</u> represents one of a plurality (e.g. four) of flight configurations; <u>a</u> represents one of a plurality (e.g. seven) of accelerometers, and <u>h</u> represents one of a plurality (e.g. three) of harmonics. The phases are transformed from

30 degrees into radians. The data is then transformed from trigonometrical notation into complex number notation (with real and imaginary parts).

B1/ <u>Identification of defects, if any, of the rotor 6</u>

35 C1/ <u>Calculating the adjustment values</u>

The helicopter 1 possess a neural network R characterized by its connection weights. Let γ be the

vibration vector measured on the helicopter 1 while the rotor 6 is poorly adjusted, with the vector α corresponding to the optimum parameters minimizes the following relationship:

5

$$F(\alpha) = \left\| R(\alpha) + \gamma \right\|^2$$

It is necessary to calculate the gradient B of the function F relative to α:

$$B = \frac{\partial F}{\partial \alpha} = \frac{\partial \left\| R(\alpha) + \gamma \right\|^2}{\partial \alpha}$$

The value of α at an iteration $\underline{i}$ is written αi.

10   For an iteration $\underline{i}$, the updating of the adjustment parameter vector is written as follows:

$\alpha i = \alpha(i - 1) + N.Bi$, where N is the down step size.

Iterations are repeated so long as F is above a particular threshold (threshold that needs to be

15   determined during design).

D1/ Weighting

In order to achieve an optimum adjustment relative to the use and to the behavior of the helicopter 1, it is

20   necessary to introduce weighting into the above-mentioned function F. It must be possible to perform weighting depending on:

· flight configurations;

· accelerometers; and

25   · harmonics.

The function F is then written:

$$F(\alpha) = \sum_c \lambda_c \sum_a \lambda_a \sum_h \gamma_h \left\| R_{c,a,h}(\alpha) + \gamma_{c,a,h} \right\|^2$$

where $R_{c,a,h}(\alpha)$ is the output cell corresponding to harmonic $\underline{h}$ of accelerometer $\underline{a}$ of configuration $\underline{c}$.

30   Furthermore, in order to adjust the tail rotor 10 of a helicopter, said step I/a) of taking said first series of measurements, and said step II/a) of taking said second series of measurements are performed with the

helicopter 1 on the ground and with the tail rotor 10 in operation.

Under such circumstances, implementation of above-mentioned step II/b) of the method in accordance with the invention comprises the following operations:

A2/ File processing

Since the reference position of the rotor is different for each helicopter 1, it is necessary to reset the measurements so as to conserve the same origin. Let α be the angle (positive in the direction of rotation) between the reference position and the reference blade, giving:

$$\varphi'_a = \varphi_a - \alpha$$

where φ' and φ are the phase of the vibration level before and after resetting, respectively, a = 1 or 2 representing the accelerometer. Phases are transformed from degrees into radians. The data is then transformed from trigonometrical notation into complex number notation (with real and imaginary parts).

B2/ Identifying the defects, if any, of the rotor 10

C2/ Calculating the adjustment values

The adjustment algorithm is identical to the algorithm for adjusting the main rotor 6 (above-mentioned operation C1).

D2/ Weighting

In order to achieve optimum adjustment relative to the use and the behavior of the helicopter 1, it is necessary to introduce weighting of the function F. It must be possible to apply weights depending on accelerometer.

The function F is then written as follows:

$$F(\alpha) = \sum_a \lambda_a \left\| R_a(\alpha) + \gamma_a \right\|^2$$

where $R_a(\alpha)$ is the output cell corresponding to accelerometer $\underline{a}$.

In addition to being capable of being displayed by the means 19, the adjustment values of the adjustment parameters as determined by the calculator 15 can also be stored in a memory 30 which is connected via a connection 31 to said calculator 15, and they can be used subsequently, e.g. for making comparisons.

In the context of the present invention, it is also possible to perform a resetting stage subsequently, in which:

a) a third series of measurements is taken during which the adjustment values of only some of said adjustment parameters are varied; and

b) said neural network is adjusted on the basis of said third series of measurements for the corresponding relationships which relate to the adjustment parameters whose adjustment values were varied.

Consequently, the method in accordance with the invention also presents the following advantages:

· the adjustments to be applied are calculated in a single step;

· the adjustments are obtained from one or two flights, which limits the time during which the helicopter 1 is unavailable; and

· it is self-adaptive, i.e. the neural network can be adapted without specific additional flights (using the ordinary flights for performing final adjustments of the helicopter), such that said network gives the best representation of the behavior of the new helicopter.